COST FUNCTI[illegible]

(Cost Considerations in Systems Analysis)

G. H. Fisher

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COST FUNCTIONS AND BUDGETS*
(Cost Considerations in Systems Analysis)

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INTRODUCTION

The President of the United States held a news conference on August 25, 1965. One of the most significant things he said was the following:

> This morning I have just concluded a breakfast meeting with the Cabinet and with the heads of Federal agencies and I am asking each of them to immediately begin to introduce a very new and very revolutionary system of planning and programming and budgeting throughout the vast Federal Government, so that through the tools of modern management the full promise of a finer life can be brought to every American at the lowest possible cost.†

The era of program budgeting had begun for the entire Federal Government. In effect what the President said was: "I want all department and agency heads to try to do what McNamara and Hitch have been attempting in Defense since 1961."

Even in 1961 program budgeting was not new--at least in basic concept. It had been proposed for the Department of Defense as early as 1953.‡ And prior to that something akin to program budgeting had been

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*A draft paper to be presented to a conference on the Economic Analysis of Public Products at Princeton University in April 1968. The conference is to be sponsored by the Universities-National Bureau of Economic Research Committee on Production and Distribution of Public Products.

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†The New York Times, August 26, 1965.

‡David Novick, Efficiency and Economy in Government Through New Budgeting and Accounting Procedures, R-254 (Santa Monica, Calif.: The RAND Corporation, 1953).

used in the War Production Board in World War II.* Its use in industry apparently dates back to at least 1924.**

But in spite of this history, the President's announcement in the summer of 1965 did pose something of a "revolution" for many departments and agencies in the Federal Government. In terms of the ultimate goal, planning, programming and budgeting would have to become an integrated process--something which (surprisingly) was not generally true at that time. The "pure requirements" approach to planning would have to be modified. Staunch advocates of new programs could no longer argue effectively in terms of: "We need new program X because there is a requirement for it; there is a requirement because we need it"; and so on.

In the planning process, alternatives would have to be examined systematically, subject to realistic resource constraints. And alternative programs under consideration would have to be "costed out" to reflect their complete incremental resource impact for the long-term future--not merely the "down payment" as portrayed by next fiscal year's conventional budget.

All of this sounds commonsensical enough. It is basically very similar to what economic planners have been talking about for years. In its simplest terms, program budgeting is primarily the identification and systematic examination of objectives and the alternative ways of achieving them. The main focus is on <u>output</u>-oriented programs or "packages of public product," not the input orientation of the conventional budget which stresses personnel, equipment, facilities, transportation, travel, contractual services, and the like.

In terms of the current jargon, the very heart of program budgeting is contained in the term "systems analysis." While systems analysis cannot be defined with precision, the following would probably be accepted as a reasonably adequate description by most of the practitioners today:

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*David Novick (ed.), <u>Program Budgeting: Program Analysis and the Federal Budget</u> (Cambridge, Mass.: Harvard University Press, 2d ed., 1967), pp. xvi-xix.

**<u>Ibid</u>., pp. xxi-xxii.

> Systems analysis may be defined as inquiry to assist decision-makers in choosing preferred future courses of action by (1) systematically examining and re-examining the relevant objectives and the alternative policies or strategies for achieving them; and (2) comparing quantitatively where possible the economic costs, effectiveness (benefits), and risks of the alternatives. It is more a research strategy than a method or technique, and in its present state of development it is more an art than a science. In sum, systems analysis may be viewed as an approach to, or way of looking at, complex problems of choice under conditions of uncertainty.*

The foregoing provides the necessary frame of reference for the discussion of the main subject of this paper: "Cost Functions and Budgets." Perhaps in view of such a framework a more descriptive title would be "Cost Considerations in Systems Analysis." In any event, the latter is the perspective we shall stress.

THE KEY ISSUES

In discussing cost analysis as a part of systems analysis, it would seem that we could segregate the main issues into two categories:

1. The conceptual problems.
2. The practical problems involved in establishing cost analysis capabilities in the Federal Government and elsewhere.

Both of these are important. But at the present time there appears to be a special interest and sense of urgency regarding category (2). We shall therefore stress (2) in this paper. Before turning to such a discussion, however, let us outline briefly some of the characteristics of the necessary conceptual framework for a cost analysis capability to support systems analysis studies.

THE CONCEPTUAL FRAMEWORK

In large measure the basic concepts underlying systems (program) cost analysis draw very heavily on concepts taken from economic theory and analysis.

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*For a further discussion of systems analysis, see E. S. Quade and W. I. Boucher, Systems Analysis and Policy Planning: Applications in Defense (New York: American Elsevier, 1968), Chap. I.

A representative, but far from complete, listing of these basic concepts is as follows:*

1. An explicit relationship between inputs and outputs, with a strong emphasis on output-oriented identifications.
2. A strong emphasis on economic (not accounting) costs. Fundamentally this means the concept of opportunity cost.
3. As a further elaboration of (2) is the requirement to deal with such concepts as:
   a. Marginal or incremental (and hence "sunk") costs.
   b. Fixed and variable costs.
   c. Recurring and non-recurring costs.
   d. Joint costs.
4. Explicit treatment of uncertainty. Simple "expected value" models very often will not suffice.
5. An awareness of scaling considerations. As in economic theory, many problems dealt with in systems cost analyses do not scale up or down in a simple fashion.
6. Explicit treatment of problems associated with time--e.g., the problem of time preference.
7. A strong emphasis on comparative analyses of alternatives--e.g., fixed cost (budget) comparisons and/or fixed utility (effectiveness) comparisons.
8. A recognition of the importance of sensitivity analysis contingency analysis, a fortiori argument, and the identification of new alternatives as ways of assisting in the all important search for dominances.**

These eight points represent some of the most important characteristics of the conceptual framework for cost analysis in support of systems analysis studies. From a purely conceptual point of view, there would seem to be little room for argument about the relevance of these concepts. The main issues arise when the cost analysts try to implement the basic ideas. Let us consider two examples briefly.

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*The ordering in no way reflects relative importance. Also, many of the items are interrelated. Finally, in some instances it is not clear that the particular point being made is conceptual or methodological--a distinction that is very often difficult to make.

**Perhaps this point is more methodological than it is conceptual. We include it in the list anyway, because of its central importance in systems analysis. (Also, it is strongly related to (4)--explicit treatment of uncertainty.)

Most analysts agree that in principle the matter of time preference should be treated explicitly. The disagreement arises over how this should be done--for example, with respect to what discount rate seems most appropriate for equalizing cost streams over time. Numerous seminars and conferences have been held on the subject of discounting, and the issue is still unresolved.* Many analysts feel that it cannot be completely resolved and that in most instances the matter is less consequential than many of the other cost analysis problems.

In fact, the analyst can do a great deal to sharpen the intuition and judgment of the decisionmakers** without resolving the rate issue. For one thing, the analyst can point out to the decisionmakers that an "undiscounted" situation usually does not exist. A case in point occurs in the Department of Defense where cost streams are projected 10 or 15 years into the future "without equalizing them for time preference." Here, the analyst can make the time preference assumption explicit: namely, a zero percent discount rate for 10 or 15 years and a very high rate thereafter. He can also calculate cases built on a reasonable range of time preference assumptions and show the impact on final results (the ranking of the alternatives being considered). Finally, he can compute the "breakeven point"--i.e., the case containing that discount rate which would have to be used to make the present value of two alternatives equal.

As a second illustration, let us consider the concept of opportunity cost. Again, there would seem to be little argument about the concept itself. Opportunity costs are generally recognized as being relevant in the examination and evaluation of alternative future courses of action. They are certainly much more relevant than, say, accounting-type costs generated for fiduciary financial management purposes.

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*Recently a survey was made of 23 Federal agencies to obtain information on discounting techniques used in making evaluations of future government programs. One of the results is that the rates used vary from about 3 to 12 percent. See statement by Elmer B. Staats, Comptroller General of the United States, before the Subcommittee on Economy in the Government, Congressional Record - Senate, January 30, 1968, pp. S632-S634.

**To sharpen the intuition and judgment of the decisionmakers is the primary role of systems analysis. Generally speaking, an analysis cannot make the decision. (E.g., see A. C. Enthoven's statement contained in an article in Business Week, November 13, 1965, p. 189.)

Problems arise, however, when the analysts attempt to apply the concept of opportunity cost in systems analysis studies. For example, the cost analysts often generate estimates of the dollar costs of various program or system alternatives being considered in long-range planning deliberations.* Such estimates may be expressed in terms of time-phased expenditures and/or obligational authority, or in terms of "static" indexes of total system or program cost.** The specific issue is: Do these dollar cost estimates adequately reflect the opportunity costs (benefits foregone) of the alternatives being examined--at least for the purposes of the types of comparisons made in systems analyses?

Probably not in all cases. However, most of the experts seem to think that for the purposes of comparing distant future alternatives, dollar costs <u>do</u> provide a reasonably appropriate index of opportunity costs in many applications. This point of view is argued vigorously, and rather convincingly, in the context of the Department of Defense by Hitch and McKean:

> If we examine the problem of planning future programs from the standpoint of the Defense Department, it seems fairly obvious that money costs are pertinent. The Department faces a budgetary constraint. For the most part it does not face a limitation on particular weapons or supplies but can buy more of them by paying their prices. What does the Department give up in order to implement one course of action? The answer is money--or, to go one step further, the alternative weapons or supplies that could otherwise be purchased. The Department could substitute one item for another by paying the price of the one instead of paying the price of the other. Dollar costs do reflect what must be given up in order to adopt a particular policy. They reflect real sacrifices by the Department because the prices of different items show the rates at which they can be substituted for each other.
>
> This is not to say that money costs perfectly represent resources sacrificed by the Defense Department. The prices of goods to be bought in the future are uncertain. One course of action may itself drive up the price of particular weapons

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*Other measures of cost are also calculated--e.g., manpower.

**That is, the sum of development (if any) and investment costs plus a number of years operating cost.

> or materials, and it is not possible to predict these effects with complete accuracy. The characteristics and cost of some items will change as technology advances. The quantity of some exceptional items may literally be fixed, or nearly fixed, even if we are looking several years ahead. Nonetheless, imperfect as it is, the money cost of a future program usually shows the sacrifice that would be required of the Department better than other measures of cost. While dollars do not precisely measure the real sacrifices, costs in terms of metals and manpower would be grossly misleading. Saying that airplanes cost so much aluminum and ships so much steel plate does not tell us how one may be exchanged for the other. Saying that each costs so many dollars adheres more closely to the facts, namely, that the services can, in making future plans, trade one for the other.*

Our concern in this paper is not so much whether Hitch and McKean are correct. Rather the point is that the issue under consideration pertains more to the matter of <u>implementation</u> of a concept rather than to the relevance of the concept itself. It is generally recognized that economic cost is one of the relevant considerations to be taken into account in systems analysis studies. The question is how to do it in practice.

This leads to our next subject: cost analysis in support of systems analysis in practice. How is it done? What are some of the problems?

COST ANALYSIS IN PRACTICE

In general terms the central problem facing cost analysts is to develop methods and techniques which will permit assessment of the

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*Charles J. Hitch and Roland N. McKean, <u>The Economics of Defense in the Nuclear Age</u> (Cambridge, Mass.: Harvard University Press, 1960), p. 26.

The above quotation is concerned with dollars as a proximate measure of economic cost from the viewpoint of the Department of Defense. What about from the standpoint of the nation? Hitch and McKean consider this question, and argue the case by means of an illustrative example. (See <u>ibid</u>., pp. 27-28.) Their general conclusion is:

> As a consequence, money costs of <u>future</u> defense activities approximate the real alternatives that are foregone--the real sacrifices that are entailed--when one activity or weapon system is selected. This will be true for those problems in which a general monetary constraint is proper, that is, for problems pertaining to dates sufficiently in the future to permit the production and procurement of varying quantities of weapons and materiel. (<u>Ibid</u>., p. 28.)

resource impact of proposed alternative output-oriented programs and/or alternative combinations (mixes) of future programs.

The basic characteristics of such a cost analysis capability stem directly from the conceptual framework discussed in the preceding section. A few of the more important of these characteristics are as follows:

1. While most of the basic estimating work must be done on the input side in terms of manpower, equipment, facilities, supplies, etc., the results of a cost analysis must be packaged in the form of output-oriented entities which are of prime concern to the long-range planning decisionmakers.

2. Cost analysis procedures (models) must be "open-ended" with respect to key performance and other variables which characterize the class of output-oriented entities under consideration. This facilitates doing parametric-type analyses which are of prime importance in extending the range of alternatives that can be examined, in making *a fortiori* arguments, in making sensitivity tests, in exploring scaling factors, and the like.

3. Related to (2) is the requirement to deal explicitly with the problem of uncertainty. Parametric cost models help by facilitating the computation of a range of cost estimates (rather than "point" estimates alone),* and by permitting determination of the sensitivity of total system or program cost to variations in the values of key parameters about which we are uncertain.

4. Both (2) and (3) imply the need for cost analysis models which are in part automated. If a large number of cases are to be computed within a reasonable amount of time and effort, manual calculation alone is usually out of the question.**

5. A strong emphasis must be placed on developing cost analysis procedures which will permit assessment of incremental costs--i.e., the additional costs implied by the proposed future course of action under consideration. The costs of past actions ("sunk" costs) and the costs of firmly committed ("locked-in") future actions must be excluded.

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*For example, "high," "medium" and "low" cases.

**In some instances a tremendous number of individual calculations are required for a single case. For example, the total force structure cost model developed by The RAND Corporation to assess the resource impact of a projected total Air Force plan over a 10-year period makes about 500,000 computations for the typical single case.

6. Finally--and perhaps most important of all--a substantial amount of time and effort must be devoted to the continuous development and maintenance of an appropriate data base: i.e., information on past, current and near future programs to serve as a basis for the derivation of estimating relationships to be used in projecting to the distant future.

We have stressed the prime importance of "output-oriented entities" or "program packages." What does this mean in areas of specific application? In the case of the Department of Defense these entities are by now rather widely recognized as being weapon and support systems and force mixes of such systems. What about the non-military realm? The following are a few examples.

In the transportation area output-oriented entities may be various future modes of transportation--rail systems (surface and subsurface), "automated" freeway systems, airlift systems, etc., and mixes of these modes. In the mental health area the planners may be interested in such things as alternative systems for dispensing mental health services (e.g., community mental health centers), alternative programs for narcotic and drug abuse, etc. In the National Aeronautics and Space Administration the prime concern is with alternative ways of attaining certain goals in space--e.g., alternative space systems for performing future missions in the lunar, earth-orbital, and planetary areas.

In any event, the cost analyst must be able to conduct his studies in terms of the types of identifications or "planning units" that are of primary interest to the long-range planners. This is just as true in non-national security problem areas as it is in defense, and the basic problems are very similar.

Let us now consider a few hypothetical examples to illustrate some of the types of output from the cost analysis process which are useful in systems analysis. In these illustrations the "output-oriented entities" are assumed to be alternative system or program package proposals being considered in the long-range planning process.

A very useful output of the cost analysis process (an input to systems analysis) is a cost function relating projected total system

(program) cost* to the size (cumulative number of units) of a proposed future course of action. An example is shown in Fig. 1. Here, total system cost is increasing at a decreasing rate, and hence marginal cost (the cost of an additional unit) is a decreasing function of the cumulative number of units. This is portrayed in Fig. 2.

Cost functions expressing total system cost as a function of cumulative number of units are particularly useful in a fixed budget comparative framework of analysis. Here, the systems analyst often wants to know: "How many units of the various alternatives under consideration can I get out of certain stipulated future budget levels?"**

An example is presented in Fig. 3 for alternatives A and B. If the specified cost level to be used in the comparative analysis is \$8 billion, 11.5 units of alternative A or 7 units of alternative B are obtainable. This is a key output of the cost analysis, which then becomes a major input to the effectiveness (utility) analysis.

Notice that in this illustration the results do not scale linearly with respect to changes in the stipulated cost level. For example, if L_1 is increased by 50 percent to L_2 = \$12 billion, the outcome is 22 units of A or 12 units of B. The increase in the number of units is greater than the increase in L_2 over L_1:

$$L_2/L_1 = 12/8 = 150\%$$
$$A_2/A_1 = 22/11.5 = 191\%$$
$$B_2/B_1 = 12/7 = 171\%$$

*Here, total system (program) cost is defined as development (if any) plus initial investment plus a fixed number of future years operating cost. Oftentimes the number of years operation is treated parametrically to see whether the assumption about this factor impacts significantly upon final results (the ranking of the alternatives being considered).

**This is one example of why cost functions relating cost to the scale of proposed future programs are useful in systems analysis work. Many of the cost functions emphasized in conventional economic theory relate cost to rate of output. Rate-of-output cost functions are also useful in certain types of problems in systems analysis. For example, in studying alternative configurations of proposed community mental health centers, we might want to examine how unit costs change as daily out-patient capacity rate is varied over a relevant range. In the case of military aircraft systems the analyst often examines how system cost (for a fixed force size) changes as the activity rate (e.g., flying hours per aircraft per month) is varied over a certain range.

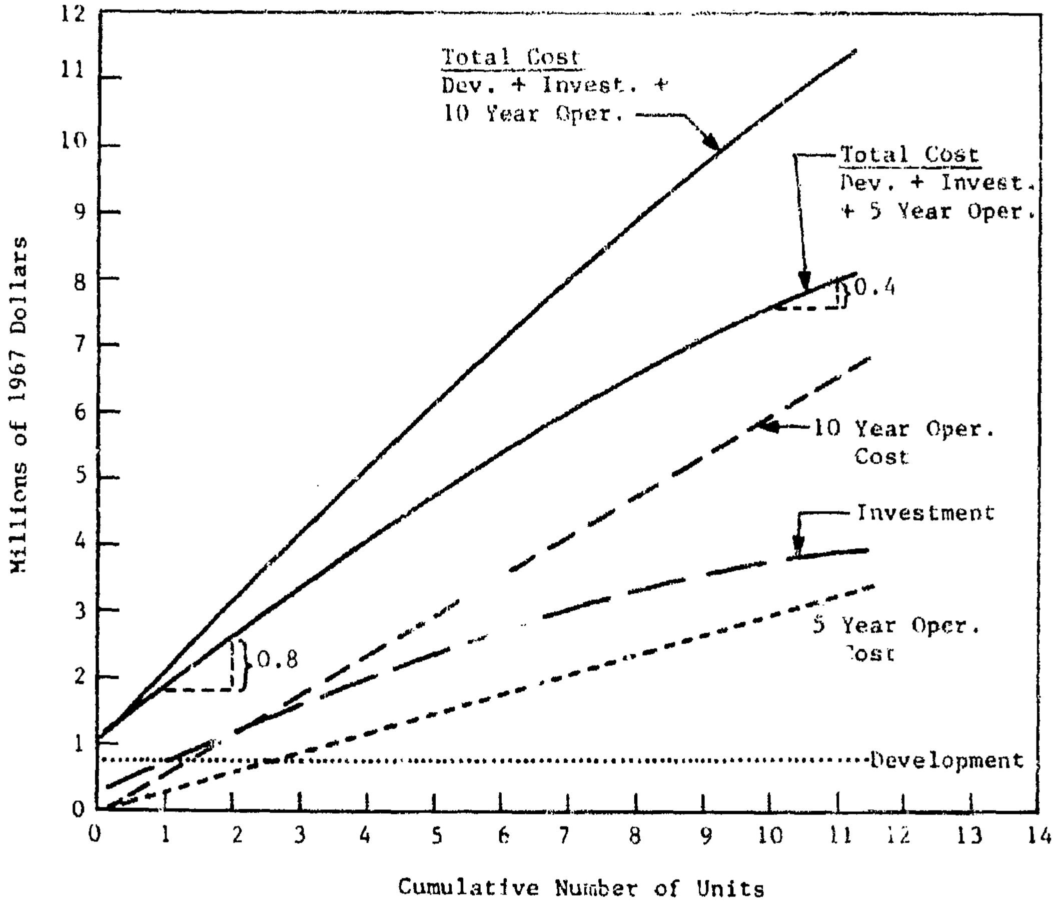

Fig. 1--System cost vs. program size

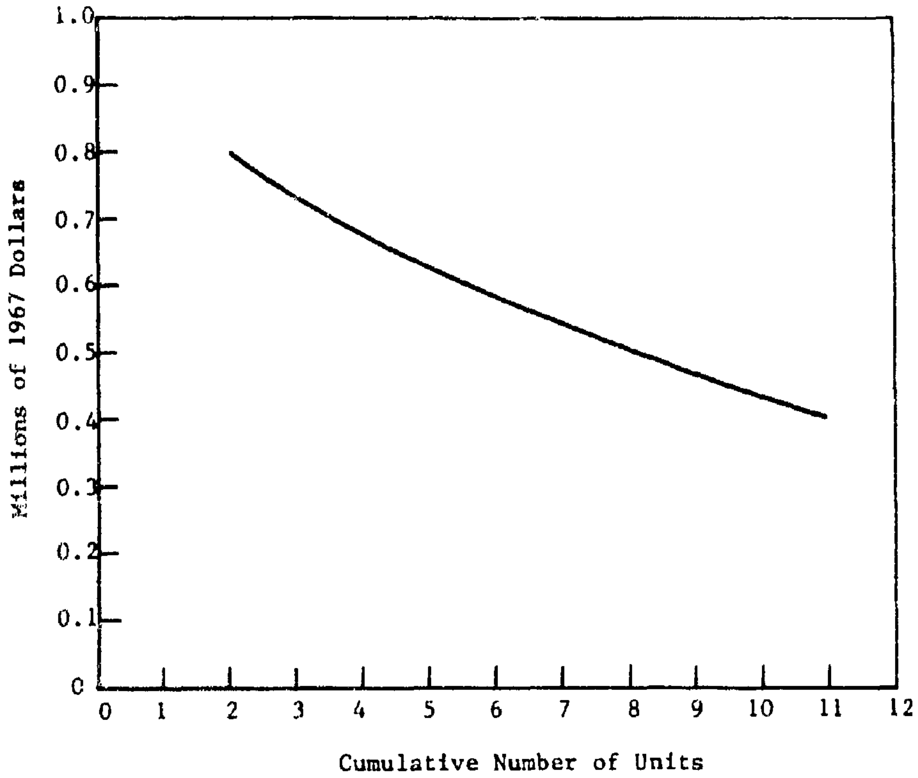

Fig. 2--Marginal cost curve (Based on total development, investment, and 5-year operation curve contained in Fig. 1)

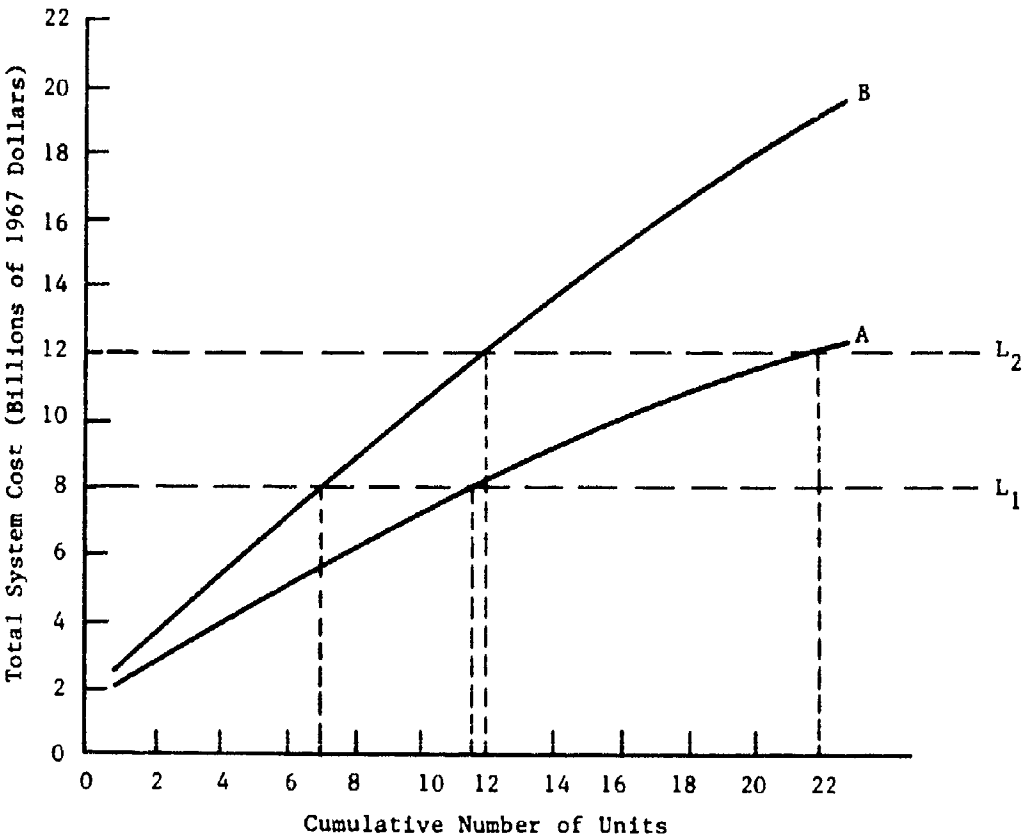

Fig. 3--Total system cost vs. program size for alternatives A and B

In a simple way this demonstrates that in the context of a fixed budget framework of analysis, scaling considerations suggest the desirability of conducting the comparisons for more than one cost level. For example, three cases might be examined: high, medium, and low.

To illustrate a somewhat different point, let us now consider a fixed effectiveness framework of analysis for comparing alternative proposed future courses of action. Here, the analysis attempts to determine that alternative (or feasible combination of alternatives) which is likely to achieve some specified level of effectiveness at the lowest economic cost. The cost analysis in effect produces the final results after the effectiveness analysis has determined how much of each alternative is required to attain the stipulated level of effectiveness.

As one simple illustration of this approach, suppose that two alternatives C and D are under consideration, and that the results of the effectiveness analysis indicate the following ranges of quantities (number of units) of C and D required to attain some specified level of effectiveness E_0:

	C	D
Low	20	4
Expected value	22	6
High	24	12

Notice that in this case the range for D is considerably greater than for C because of uncertainty.

Suppose now that the estimated total system costs as a function of cumulative number of units for C and D are as shown in Fig. 4. Taking the expected value outputs from the effectiveness analysis, we see from Fig. 4 that D is the least cost alternative for attaining effectiveness level E_0: \$7.5 billion for D vs. \$15.3 billion for C, or a factor-of-two difference in favor of D. If the uncertainties in the effectiveness analysis are taken into account, alternative D still holds up well, even in the situation where the worst case (highest cost) for D and the best case (lowest cost) for C are paired up. Thus, at least with respect to the uncertainties taken into account in the problem, alternative D appears to be a dominant solution--something which the systems analyst is always seeking, but rarely finds.

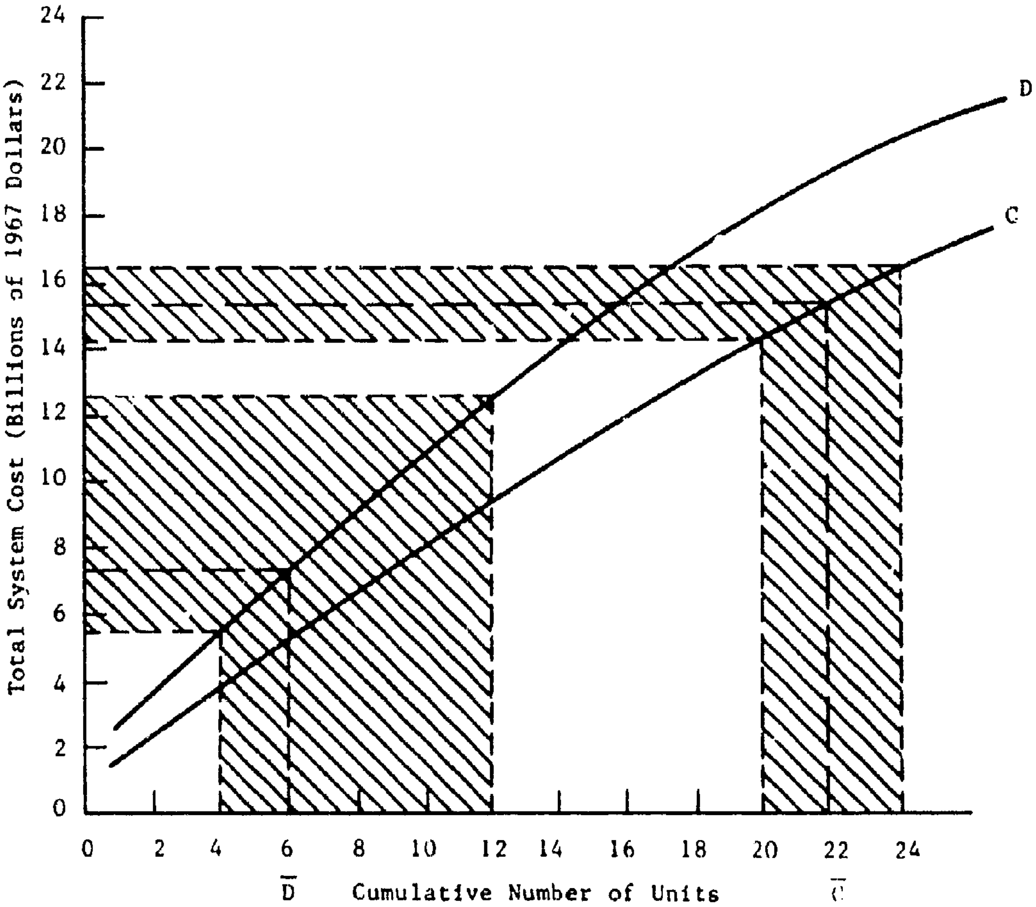

Fig. 4--Total system cost vs. program size for alternatives C and D

(Fixed effectiveness = E_0)

So far, our examples have been essentially "static": i.e., projected costs have not been treated explicitly as a function of time. In many decision contexts, however, the alternatives have to be examined in terms of time-phased cost streams projected a number of years into the future.

As an example, suppose there are two new proposed alternatives, programs E and F, which are estimated to be capable of accomplishing the same objective in the future with essentially the same degree of effectiveness for the time period of interest. (A "fixed-effectiveness over time" framework of analysis.) Suppose further that the time-phased total program costs over a 15-year period in the future are as portrayed in Fig. 5. Here, the time preference assumption is a zero discount rate for the first 15 years, and a very high rate (over 100 percent) thereafter. Notice that in each case when the yearly costs are summed over the 15-year period, the totals are the same ($9 billion each for E and F).

On the basis of the data presented so far, we have an equal-effectiveness, equal-cost situation; so presumably the decisionmakers would be indifferent regarding the choice of E or F--at least on the basis of the quantitative information available at this point.

Notice, however, that the time impacts of the costs for E and F are considerably different. The basic reason for the difference is that alternative E requires higher cost outlays (relative to F) early in the period because of greater development and investment costs. These outlays pay off in terms of an efficient operational program having relatively low operating costs later in the period. Alternative F, on the other hand, has lower development and investment costs than E. This, however, implies a less efficient operational program than E, with the result that larger operating costs are required to accomplish the specified task with the same degree of effectiveness as E. Therefore, the costs for F during the latter years of the 15-year period are about 2 times those of E.

In view of these differences in the time impact of the costs of E and F, the question arises as to whether the planners would still be indifferent regarding the choice of E or F if the time preference

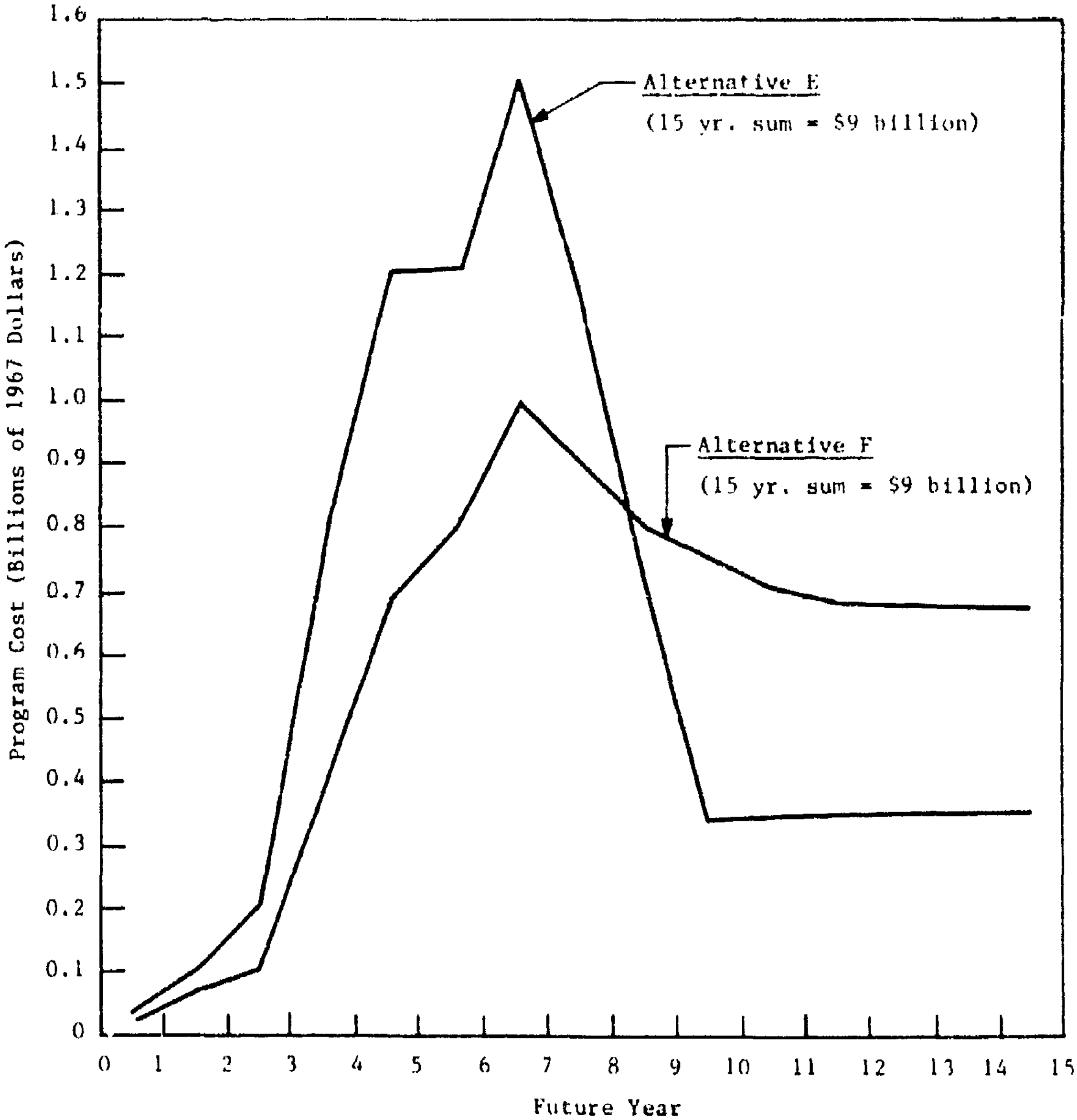

Fig. 5 -Time-phased program costs for alternatives E and F; discounted for time preference at 0.0% for the first 15 years, 100+% thereafter

assumptions are varied. Suppose the base case (Fig. 5) is modified to reflect the following time preference specifications: a discount rate of 6 percent for 15 years, and a very high rate (over 100%) thereafter. The results are as follows:

	Present Value Cost in Billions	
	Base Case (0;100+%)	First Modification (6;100+%)[a]
Alternative E - - - - - - - -	$9	$5.8
Alternative F - - - - - - - -	9	5.3
Difference - - - - - - - -	0	0.5

[a]The time-phased cost profiles for this case are presented in Fig. 6.

Thus, the first modification (6% for the first 15 years) results in a rather sharp reduction in the present value of the 15-year costs for both E and F. However, the difference between them can hardly be regarded as significant in view of the many uncertainties involved in the total analysis. The decisionmakers are likely to continue to be indifferent regarding the choice of E or F on the basis of the present values of the two cost streams.

Would this still be the case for a discount rate considerably higher than 6 percent? Let us try a 10 percent rate for 15 years, and a very high rate (over 100%) thereafter. The results are:

	Present Value Cost in Billions		
	Base Case (0;100+%)	First Mod. (6;100+%)	Second Mod. (10;100+%)
Alternative E - - - - - -	$9	$5.8	$4.5
Alternative F - - - - - -	9	5.3	3.9
Difference - - - - - -	0	0.5	0.6

The second modification results in a further reduction in the present values of the 15-year costs for both E and F. Here again it is very doubtful that the difference in present values between E and F is significant. The uncertainties in the basic problem are such that

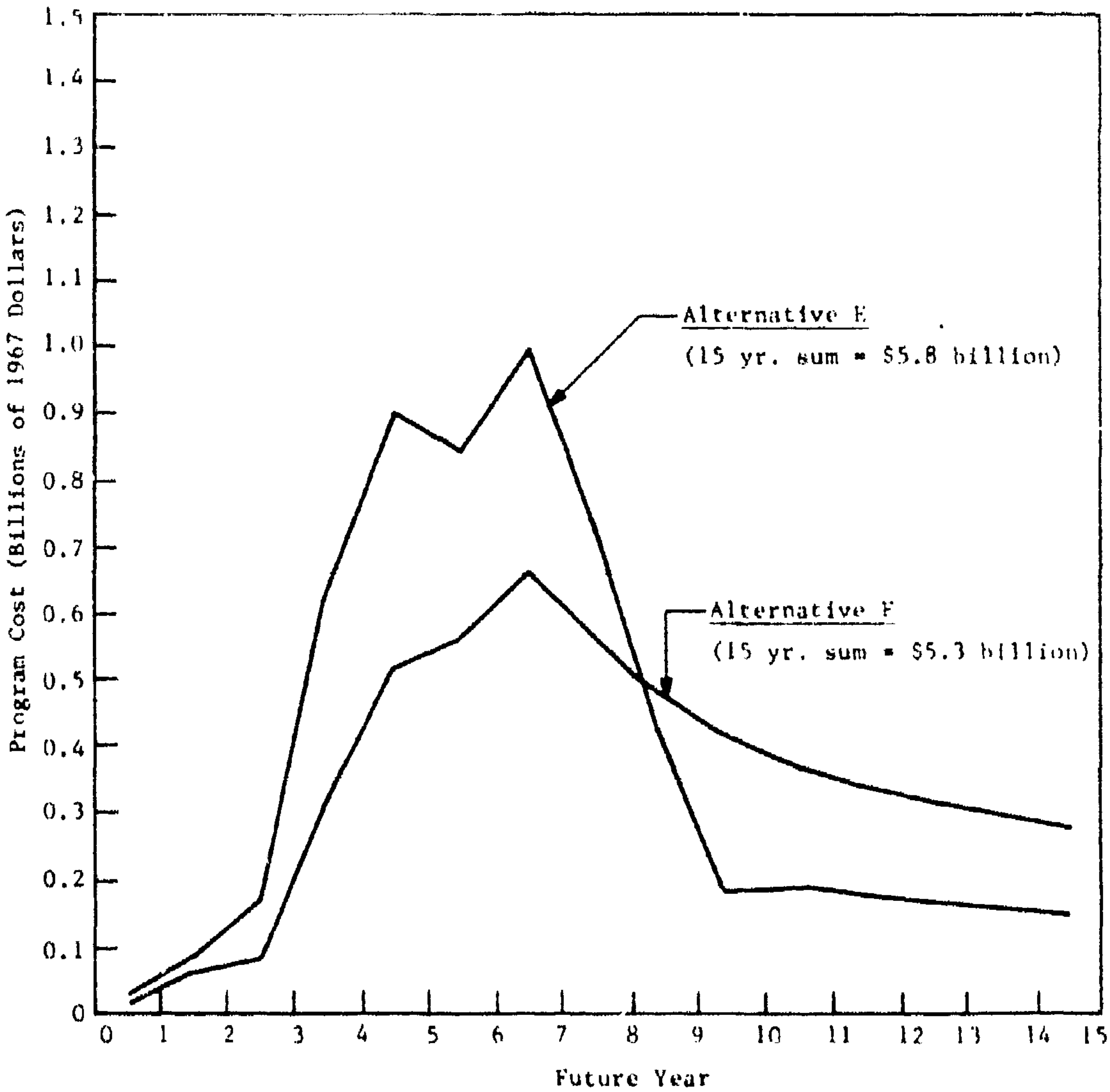

Fig. 6--Time-phased program cost for alternatives E and F; discounted for time preference at 6% for the first 15 years, 100+% thereafter

a 15 percent difference in cost is no doubt well within the "noise level" of the analysis. Also it should be pointed out that in most contexts a 10 percent discount rate for time preference is fairly high,[*] which makes makes the second modification a rather extreme case.

In sum, in this particular example, the conclusion would seem to be that the decision regarding the choice of alternative E or F is likely to be independent of the assumptions made with respect to the treatment of time preference.[**]

As a final example, let us consider the examination of variations in total system (program) cost as the characteristics of the system (program) are varied, assuming a fixed number of years of operation. This represents an important technique of analysis in systems analysis.

For an illustration, we shall use the context of the national security area and consider the case of a proposed future aircraft system where the mission requires that a fleet of aircraft be continuously airborne on a series of stations which cover a large geographical area. A Navy antisubmarine warfare (ASW) mission in the future is a possible example.

Continuously airborne alert aircraft systems typically involve a host of significant variables: endurance hours of the aircraft to be employed in the system, extent of the area coverage, nature of the

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[*] Recall that in this exercise we have been discounting for time preference only--not for time preference plus a supplemental rate for risk. When analysts apply rates like 10 to 15 percent, they usually have in mind a combined rate to allow for time preference and risk or uncertainty.

[**] Examples of other cases are the following:

Case	Present Value in Billions		
	Alt. E	Alt. F	Difference
6% for 25 yr - - - - - - - -	\$6.9	\$7.4	\$0.5
10% for 25 yr - - - - - - - -	5.0	4.9	0.1
15% for 25 yr - - - - - - - -	3.5	3.1	0.4
5% for first 10 yr 10% for next 5 yr 20% for next 5 yr 50% for next 5 yr - - -	6.6	6.5	0.1
10% for first 15 yr 50% for yr 16-25 - - -	4.6	4.2	0.4

payload requirements, aircraft maintenance policy (one, two, or three shifts), and the like. Intra-system cost analysis must usually explore the consequences of variations in these variables.

Figure 7 shows an example for a future ASW system to patrol and destroy ballistic missile-carrying enemy submarines, where aircraft endurance hours and area coverage (nautical miles out to sea from U.S. coastlines) are varied. Here total system cost is defined to be research and development + investment + five years of operation. Notice that as the area coverage is extended, the requirement for longer endurance becomes increasingly more severe.

Figure 8 contains another ASW system cost example. Here total system cost (defined as in Fig. 7) for each pound of payload (electronics, ASW missiles, etc.) on station is expressed as a function of the pounds of payload carried per aircraft.* Curves are shown for three types of aircraft that might be candidates for use in the proposed ASW system.

Notice that the use of conventional jets in this mission application results in a considerably higher minimum cost point than for long-endurance aircraft, and that system cost per pound of payload on station is very sensitive to individual aircraft payload weight. Note also that as we move to the large, long-endurance aircraft, the costs become much less sensitive to a particular loading or payload weight. This might suggest that if the size of the payload to perform the future mission is clouded by uncertainties, then flexibility may be achieved by going to the large, long-endurance aircraft.

A MAJOR DIFFICULTY: THE DATA PROBLEM

What are the main difficulties involved in doing cost analyses of the type described in the previous section? There are many--some bureaucratic, some substantive. Because of space limitations, all of these difficulties cannot be outlined and discussed here. We shall therefore

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*Area coverage is fixed at 1000 nautical miles.

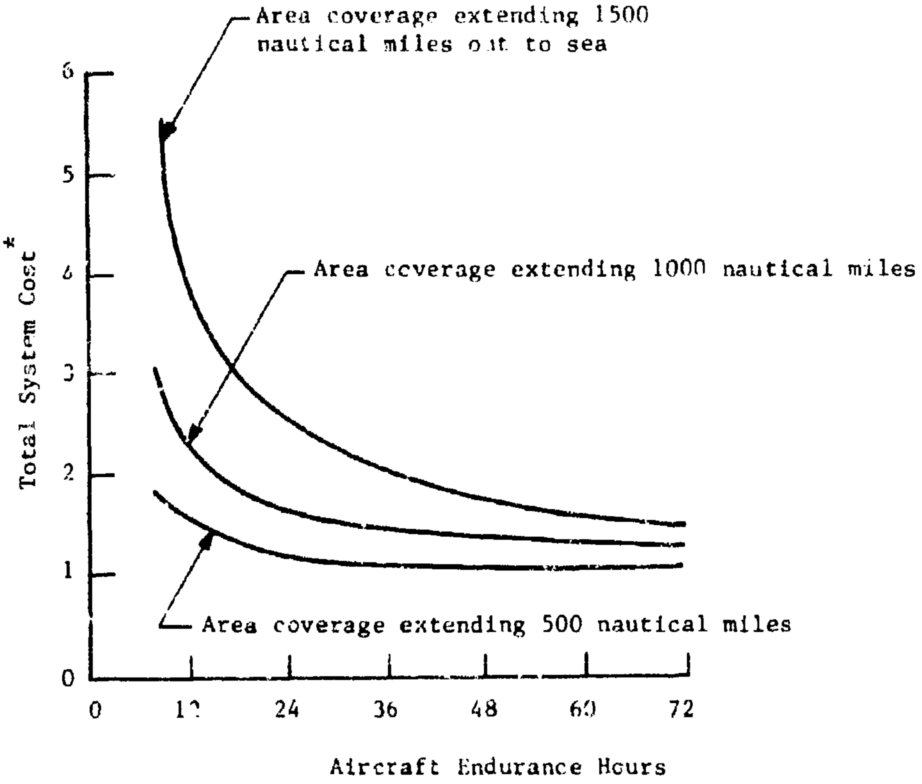

Fig. 7--ASW system cost vs. aircraft endurance for several area coverages

*Synthetic number scale

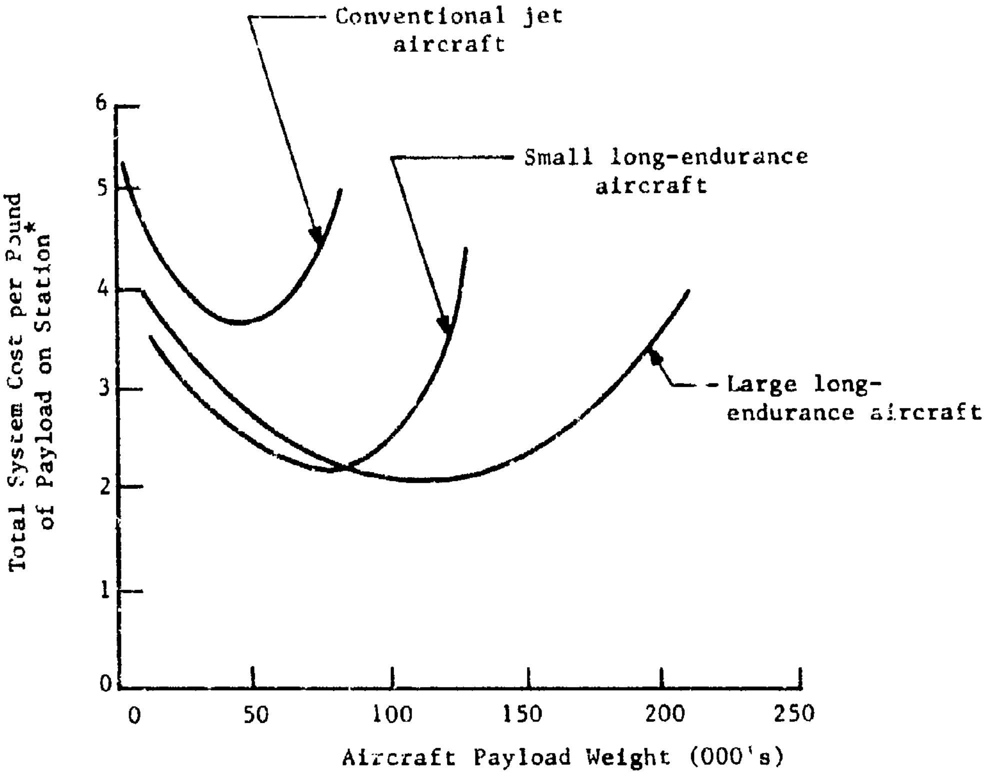

Fig. 8--System cost per pound of payload on station
vs. aircraft payload weight

(Area coverage = 1000 n.mi.)

*Synthetic number scale

take the most severe--the data problem--and treat it at some length.*

In most cases the ability to engage in cost analysis as an integral part of systems analysis studies requires the development and use of cost models. A cost model is a device for generating estimates of the resource impact of future output-oriented program packages in terms of the inputs that would be required to develop, install, and operate these proposed programs over a period of years. The input structure typically involves various categories of facilities, equipment, personnel, supplies, etc., or combinations of these items (maintenance, for example).

For each category in the input structure we must have an estimating relationship (or series of relationships) expressing cost as a function of an appropriate set of cost-generating or explanatory variables.** These estimating relationships form the very heart of a cost analysis capability.

Estimating relationships have to be derived on the basis of something. Sometimes that something has to be "experience and judgment" (preferably of an expert). Generally speaking, however, we would prefer that they be developed from statistical analyses of past, current, and near future data and information. At this point we run headlong into "the data problem." And it is a problem of fundamental importance, because a substantive cost analysis capability cannot exist without an appropriate information and data bank.

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*Much of the discussion to follow draws rather heavily on the national security area. This is because the author has had more experience in the Department of Defense than in other governmental agencies. The basic data problems, however, are very similar in all areas, and the methodological and procedural points to be made in this section are applicable to a wide variety of contexts.

**The cost of a certain type of equipment for the future may be estimated as a function of its performance and/or physical characteristics and estimated production quantity. The cost of equipment maintenance may be estimated as a function of equipment characteristics and projected activity rate.

Why Is There a Data Problem?

The reader may well wonder why the data problem is so severe. Has not the Government been developing information systems and collecting a huge volume of data in numerous areas for many years? Has not industry and other institutions been doing the same thing? How could there be a "data problem"?

These are legitimate questions. The answers are numerous and varied. Here, we shall try to select a few of the more important ones, with a view to giving the reader a reasonable degree of understanding of why a data problem exists.*

Information in the wrong format. Information systems in the Government and elsewhere have indeed generated a tremendous amount of data. In many instances, however, these data are not in an appropriate format to be very useful in a program cost analysis activity serving the long-range planning process.

The main reason for this is that these information systems were established primarily to serve the needs of managers of functional areas of operational activity (maintenance, supply, etc.), of managers responsible for fiscal integrity or fiduciary accounting requirements ("keeping hands out of the till"), of managers concerned with critical resource items across the board (e.g., personnel), of budgeteers concerned with the conventional budget, and the like. In short, the orientation of a large number of past and existing information systems is toward the input side *per se*, with little or no provision for making meaningful translations reflecting impacts on output-oriented program packages.**

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*The points discussed below relate for the most part to technical aspects of the problem. Other factors can be important also. For example, formal information and data systems are sometimes established without sufficient understanding of the relevant organizational and institutional considerations pertaining to the agency in question.

**Oftentimes the suggestion is made that if the analyst will probe the data base at successively greater levels of detail, he will eventually find the kinds of identifications he needs. Sometimes this is true. On the other hand, one is likely to find that if an information system is structured to deal in terms of, say, "object classes," then going into more detail will simply yield greater amounts of information in the same terms (object classes).

The "matching up" or integration problem. Particularly when the objective is to derive estimating relationships, the analyst must not only collect historical cost data in the right format. He must also obtain information on quantities, physical and performance characteristics, activity rates, and other types of cost-generating variables. The latter must be matched specifically to the cost data points.

Sometimes this is difficult because the information on the cost-generating variables must be extracted from different sets of records than those containing the cost data. And differing sets of records can often have dissimilar bases for reporting--for example, with respect to lot size, time period covered, and the like.

Differences in definitions of categories. A different kind of "matching up" problem frequently occurs. This concerns the lack of a one-to-one correspondence between the definition of the content of categories in the input structures set up for program cost analysis purposes, and the definition of analogous categories in the existing data and information collection systems.

It is not possible to set up the preferred input structure which will meet the requirements of cost analyses in support of long-range planning and at the same time be in complete harmony with existing data and information systems at any point in time. Differences in definition of certain categories in the input structure and their counterparts in the existing data base are therefore bound to be present. This creates a data problem for the cost analyst when he is collecting information to serve as the basis for deriving estimating relationships for various categories and sub-categories in his input structure. He will often have to make adjustments to the raw data to correct for these definitional differences.

The influence of temporal factors. Historical data are, of course, generated over time. This means that numerous dynamic factors will have influences on the information being collected in a certain area. First of all, the information collection systems themselves have a habit of changing over time--for example, the appropriate definition of the content of various categories being used to accumulate the

historical data may change as the system evolves. Also, in the case of financial data, price level changes will occur and be reflected in the information being collected over time.

In addition to these types of temporal considerations is the important fact that many Governmental agencies deal with a rapidly changing technology. both with respect to hardware and with respect to organizational and operational concepts. Almost by definition this means that even with a near perfect information collection system, only a relatively small sample of data can be generated for a given era or class of technology. In the major equipment area, for example, the analyst is lucky if he can have available 15 or 20 good data points for a certain class of hardware. He is more likely to have less than half that number.

By the nature of things, therefore, the analyst is all too often in the world of very small samples. As all good statisticians know, this poses real problems in our attempts to develop meaningful structural relationships which will permit us to project forward to distant future programs and capabilities.

So much for our listing of problem areas concerning the data base. We repeat that the four points outlined above do not represent a complete enumeration; they should, however, convince the reader that there is such a thing as a "data problem." The question now is: What do we do about it?

DEALING WITH THE DATA PROBLEM

At first thought, one might be tempted to say: "If there is a data problem, let's solve it once-for-all by establishing the information collection system to meet all our needs." People have often made statements like this. Is such a thing feasible?

We think not, for several reasons. Some of the more important of these are the following:

1. Cost analysis problems in support of systems analyses typically vary considerably from one study to another. The requirements for estimating relationships--and hence data and information requirements--

are not constant over time, or even for a given small interval of time. In short, the cost analyst who is working in support of the long-range planning process could not specify his data and information needs "once-for-all." It would be difficult, if not impossible, then, to establish the comprehensive information system.

2. Even if something approaching (1) could be done, we still have to worry about economics. Large information systems--especially those designed for complete enumerations--are very expensive. This poses a systems analysis problem in itself. Would the (large) incremental cost of a new complete enumeration information system be justified in terms of the benefits to be derived--particularly in the long-range planning context where high precision in an absolute sense is usually not a prime requirement? The answer is probably "no."*

3. In addition to points (1) and (2) is the problem of small samples arising from the fact that many Governmental agencies have to deal with a rapidly changing technology. As indicated previously, this means that in many instances only a relatively small number of observations will be available for a certain era or class of technology. Here, even a near perfect information system cannot increase the sample size.

Where does all this leave us? On the one hand, a strong argument has been advanced for the importance of an appropriate information and data base. On the other hand, trying to solve the problem once-for-all does not seem feasible, at least in a general sense. Does this mean that the situation is an impasse?

The answer is "no." The problem is susceptible to reasonable solution, at least in many instances. Numerous alternatives to establishing new complete enumeration information systems may be considered. We shall now outline and discuss briefly examples of a few of the approaches that may be taken to help solve the data problem.

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*As will be pointed out later, there are alternatives to complete enumerations on a recurring basis.

Use of Ad Hoc Sample Surveys

One very interesting possibility which the present author feels has been relatively neglected is sampling, or something akin to sampling. This can be a low cost way of obtaining information that may be very useful in deriving estimating relationships for use in long-range planning studies.

Suppose, for example, that the cost analyst is faced with the problem of developing end-product oriented estimating relationships for some functional area like maintenance or supply in the Department of Defense. Suppose further that the existing cost accounting systems accumulate historical cost data in categories such as labor, material, overhead, etc., and that no provision is made for identifications to end-product packages of military capability (e.g., weapon systems). Conceivably one solution would be to overhaul the entire formal accounting system to accumulate historical cost data in the desired form, in addition to the existing categories needed for purposes of functional management of the maintenance and supply activities. This, however, could be very expensive, and considerable time would have to elapse to permit design, test, and implementation of the new accounting system.

An alternative would be to select a few representative locations and to provide for an ad hoc (temporary) "ticketing" system to accumulate costs in terms of weapon systems for a relatively short period of time--say a month or two. The ad hoc arrangement would be supplementary to--and hence would not disturb--the existing formal accounting system. This approach has been used on numerous occasions in the past, and for those cases known to the author, the results have been good--at least for the purpose of deriving estimating relationships for long-range planning.* In any event, sampling procedures seem worthy of

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*The author has conducted simple tests in several instances where complete enumerations were available. The procedure was as follows: Take the complete enumeration as a data base and, using regression analysis, derive an estimating relationship--say $C = \hat{\alpha} + \hat{\beta}X$. Then take random samples of 15 or 20 observations from the complete enumeration and derive similar relationships on the basis of these sample data bases. Then test the resulting estimates of α and β against the values obtained from the complete enumeration to see if there is a significant difference. In the particular cases examined by the author, most of the time no significant difference existed (at the 0.05 level) between estimates of the regression coefficients obtained from the small samples and those obtained by using the complete enumeration as a data base.

consideration as an alternative to establishing new complete enumeration systems across the board.

Techniques for Assisting in Handling the Small Sample Problem

We have indicated that the cost analyst very often finds himself confronted with small samples. Can anything be done to help ease the problems arising from having to use data bases containing only a small number of observations from the historical record? Several things may be done. Let us consider two examples.

The first is an extremely simple idea, but in some instances it can help a great deal. Particularly in deriving estimating relationships for use in long-range planning studies, the cost analyst should not necessarily restrict himself to the historical record in assembling his data base. In many cases he should seriously consider increasing the number of observations by including appropriate data points based on estimates made by experts for the very near-term future, and/or by taking advantage of certain kinds of qualitative information.

Suppose, for example, we have only four data points available from the historical record (see Fig. 9). Suppose further that the analyst must derive an estimating relationship which will help him project out beyond the range of the historical sample (beyond the value X_0 of the explanatory variable). On the basis of the four data points alone, it is not very clear what kind of relationship between C and X should be postulated. For example, the curves AB and CD in Fig. 10 would seem about equally plausible. Here is a case where the cost analyst should probe further and attempt to get some sort of additional information (either quantitative or qualitative) to help him make an informed judgment.

Suppose that in our hypothetical example the cost analyst, upon further exploration, was fortunate enough to find two more data points in the form of estimates for the near-term future made by reputable experts in the field under consideration. Upon checking out the methods used to make these estimates, the cost analyst decided that it would be appropriate for him to use them as a supplement to his historical data base. The result is shown in Fig. 11. This would tend to suggest

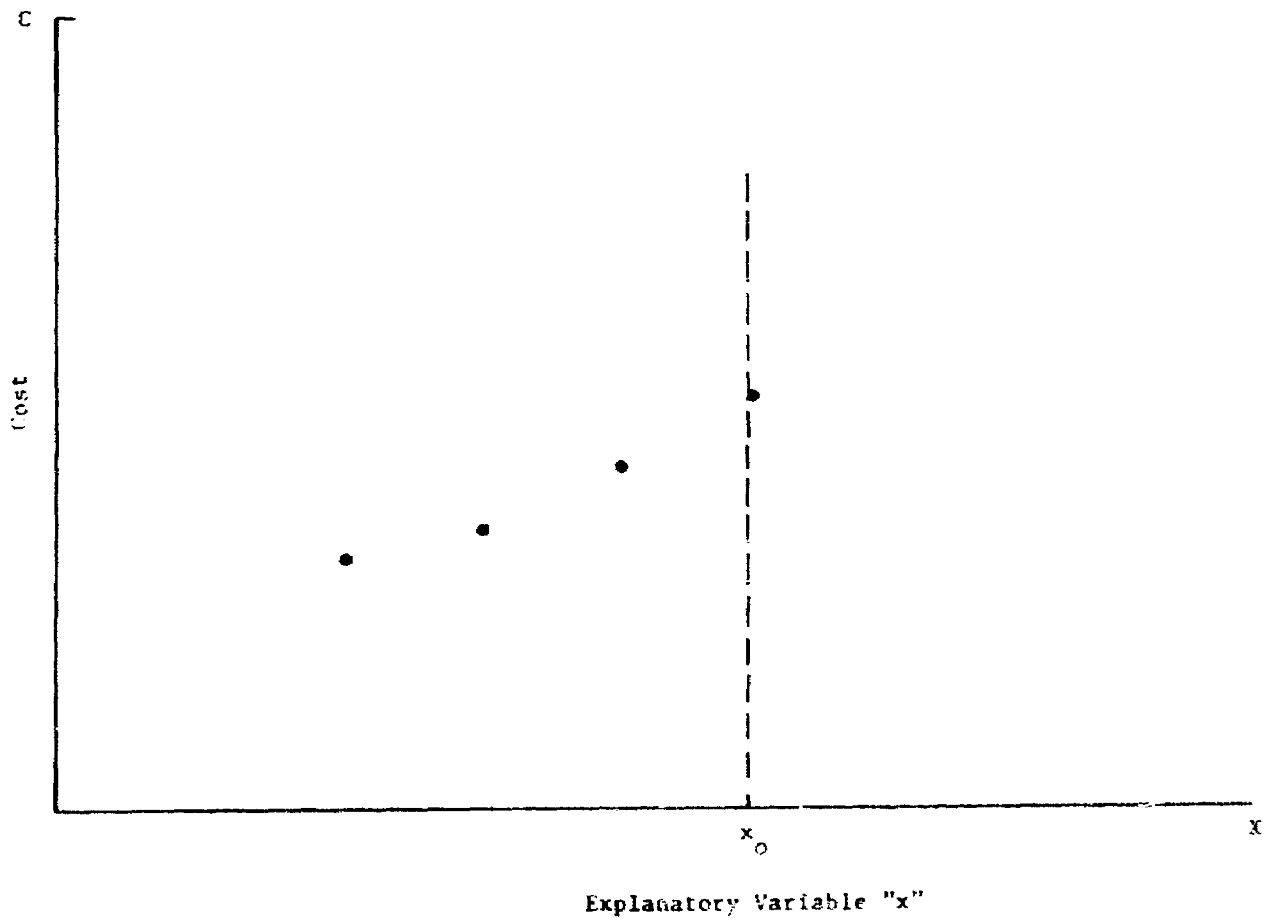

Fig. 9--Small sample example

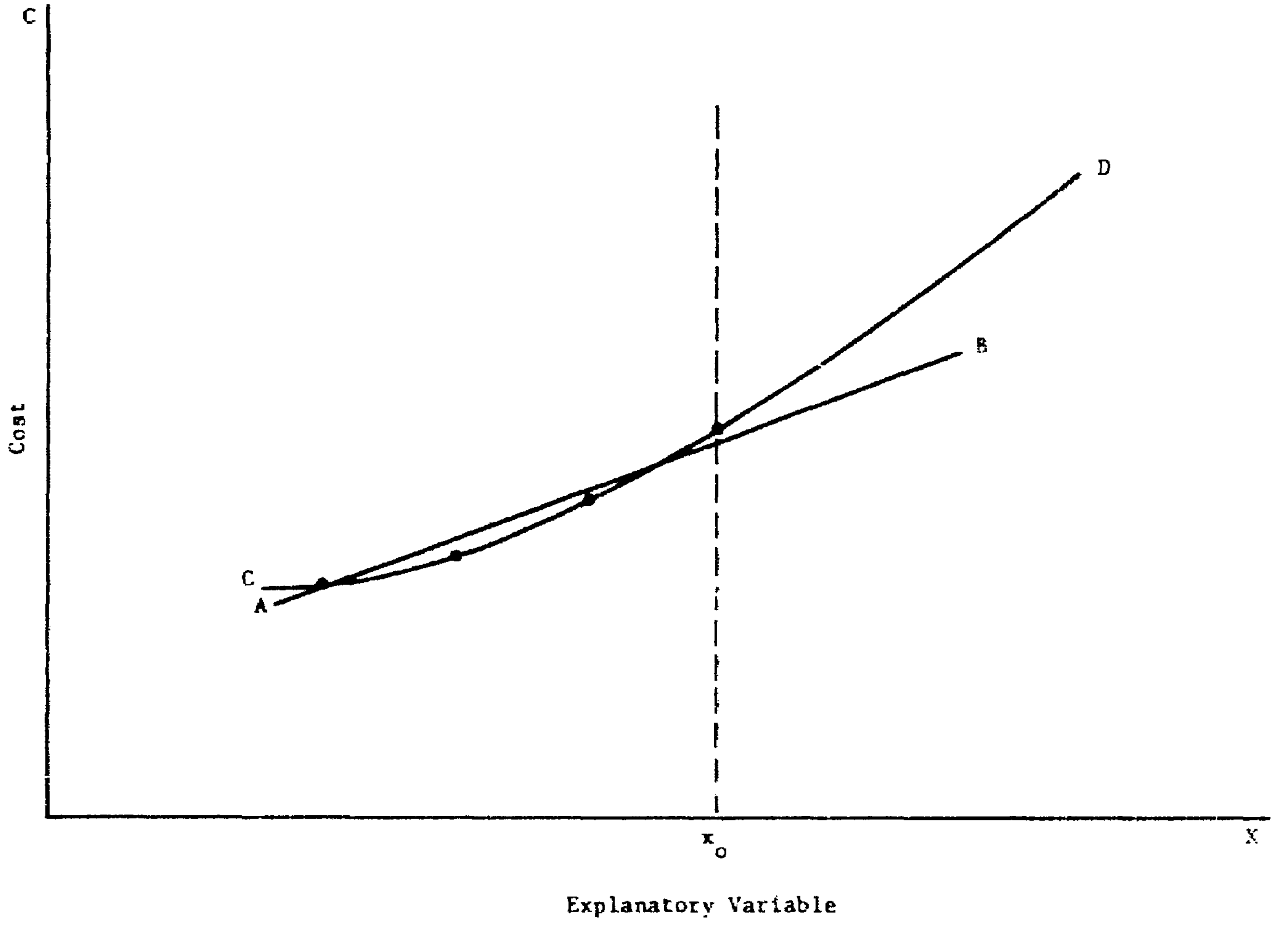

Fig. 10--Small sample example--some plausible estimating relationships

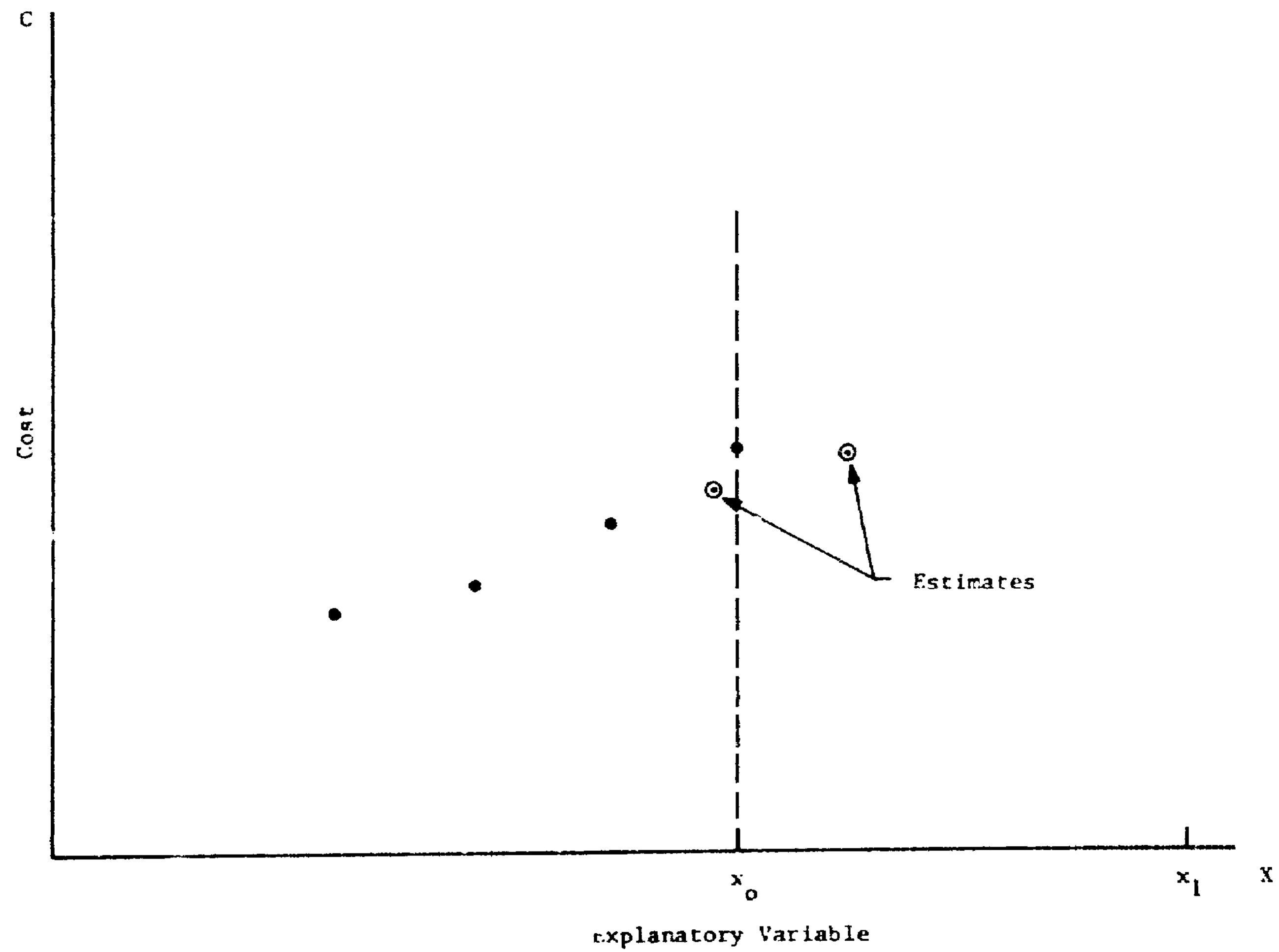

Fig. 11--Supplementing the Historical Data Base

the appropriateness of a linear hypothesis as a basis for projecting out to the vicinity of X_1 in Fig. 11.

Let us assume, however, that our cost analyst wanted still further substantiation--if possible. He recalled that in his initial search for an appropriate explanatory variable, he had talked to some engineers who were experts in designing the type of equipment or activity under investigation in this particular case. He decided to consult with them again in the hope of obtaining some thread of qualitative evidence which would help in deciding whether to accept or reject the linear hypothesis. Upon listening to the engineers discuss the structural characteristics of the activity under consideration, the cost analyst became convinced that projections for large values of the explanatory variable X should be made on the basis of a linear relationship between C and X.

This hypothetical example illustrates two points about how one can deal with very small samples: (1) Under certain conditions the size of the sample can be increased by judiciously using estimates for the near future as supplements to the historical data base; (2) it may be possible to use qualitative information to assist in deciding about what kind of estimating relationship is most appropriate.

As another example, let us consider a case where the sample is very small and we seek to gain additional information by lowering the level of aggregation one notch.

In the area of military major equipment cost analysis, cost-quantity relationships are very important. As the cumulative number of units increases, unit cost usually declines.* Suppose that we are interested in a certain type of aircraft airframe (call it X) and that we have only three data points. No other points are available for this

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*For a thorough treatment of cost-quantity relationships, see Harold Asher, Cost-Quantity Relationships in the Airframe Industry, R-291 (Santa Monica, Calif.: The RAND Corporation, July 1, 1956). Cost-quantity relationships in one form or another are also found in other areas. For example, in the automobile industry unit production costs after launching a new model are considerably higher during the earlier part of the production run than they are later in the model year. These "excess" costs are called "launching costs" in the automobile industry.

particular airframe. The log-log plot of the data base is shown in Fig. 12.

Assume now that the cost analysis is part of a systems analysis study in which large numbers of airframe X are being considered: 1000 or more. Should the analyst simply assume a log-linear relationship, connect his three data points, and extend the line out to cumulative outputs of 1000 or more? Most probably not. An experienced analyst knows all too well the dangers of mechanistic extrapolation, for scaling factor reasons and others as well.

Since in our hypothetical example the sample size cannot be increased, what can be done? One possibility is to see if additional information can be obtained by disaggregating. Suppose that our cost analyst goes back to the original data source and finds that additional detail is in fact available. He obtains a breakdown of the total airframe in terms of labor, material, and overhead. A plot of these data is shown in Fig. 13. This slight addition to the data base immediately provides useful insights into the projection problem. If we assume log-linear relationships for the components (labor, material, and overhead),* it is obvious that on the basis of the available information the total curve cannot be log-linear when projected out to large cumulative unit numbers because the materials curve has a significantly different slope than the labor and overhead curves.**

If the curves in Fig. 13 are extrapolated out to cumulative unit number 1000, the results are as portrayed in Fig. 14. Here it is clear that the cost analyst has benefited from the information obtained by disaggregating one level in the data base. Merely extrapolating out to cumulative output 1000 on the basis of the three original data points no longer seems appropriate.† The difference between the two

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*In general this is not necessarily a good assumption; but we shall use it here to keep the example simple. The argument is even stronger if the component curves are assumed to be convex on logarithmic grids.

**If the component curves are linear but nonparallel, the total curve (sum of the components) must be convex on logarithmic grids and must approach as a limit the flattest of the component curves. (E.g., see Asher, op. cit., pp. 70-72.)

†The difference would be even greater if the component curves were assumed to be convex.

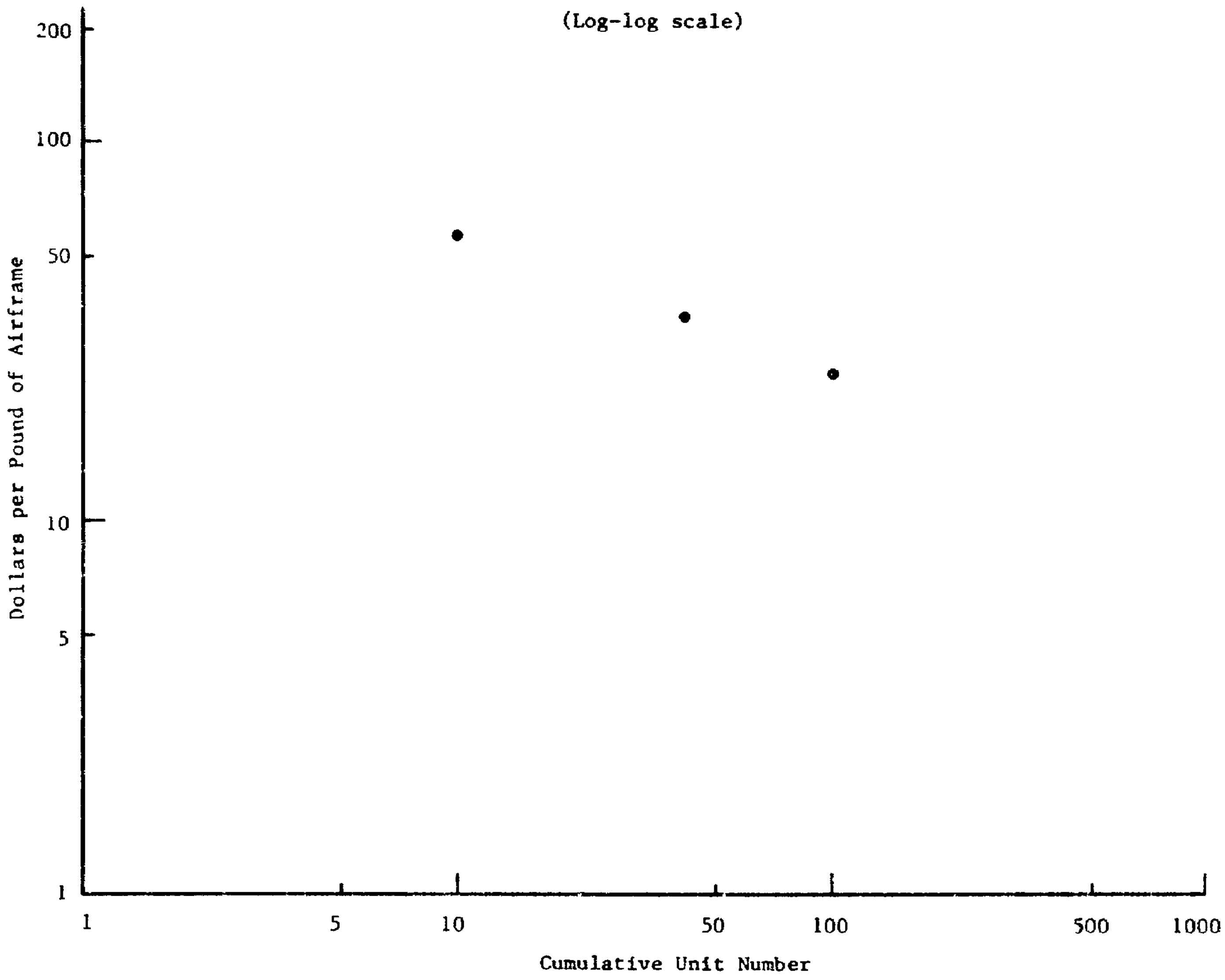

Fig. 12--Dollars per pound of airframe weight vs. cumulative unit number

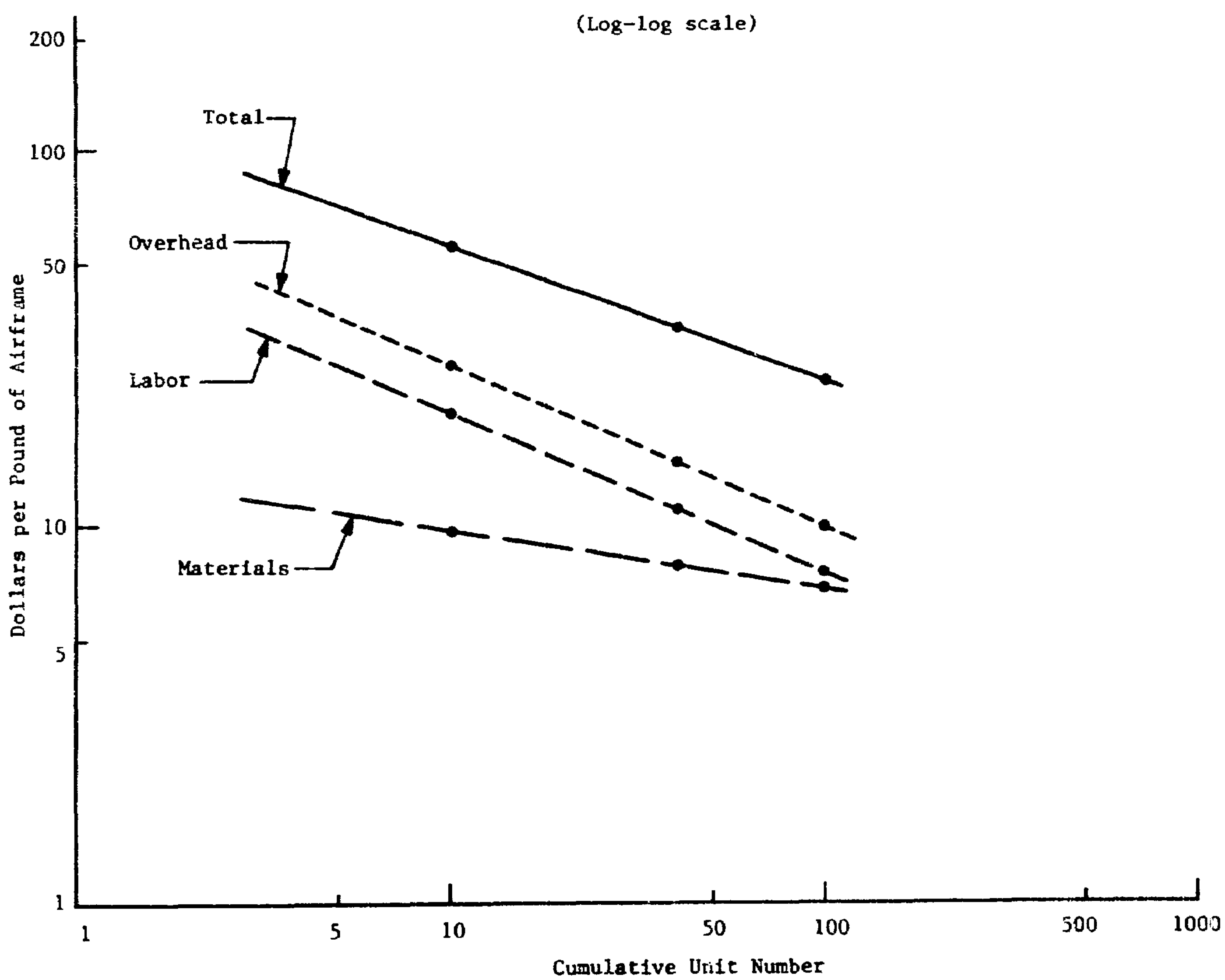

Fig. 13--Dollars per pound of airframe vs. cumulative unit number

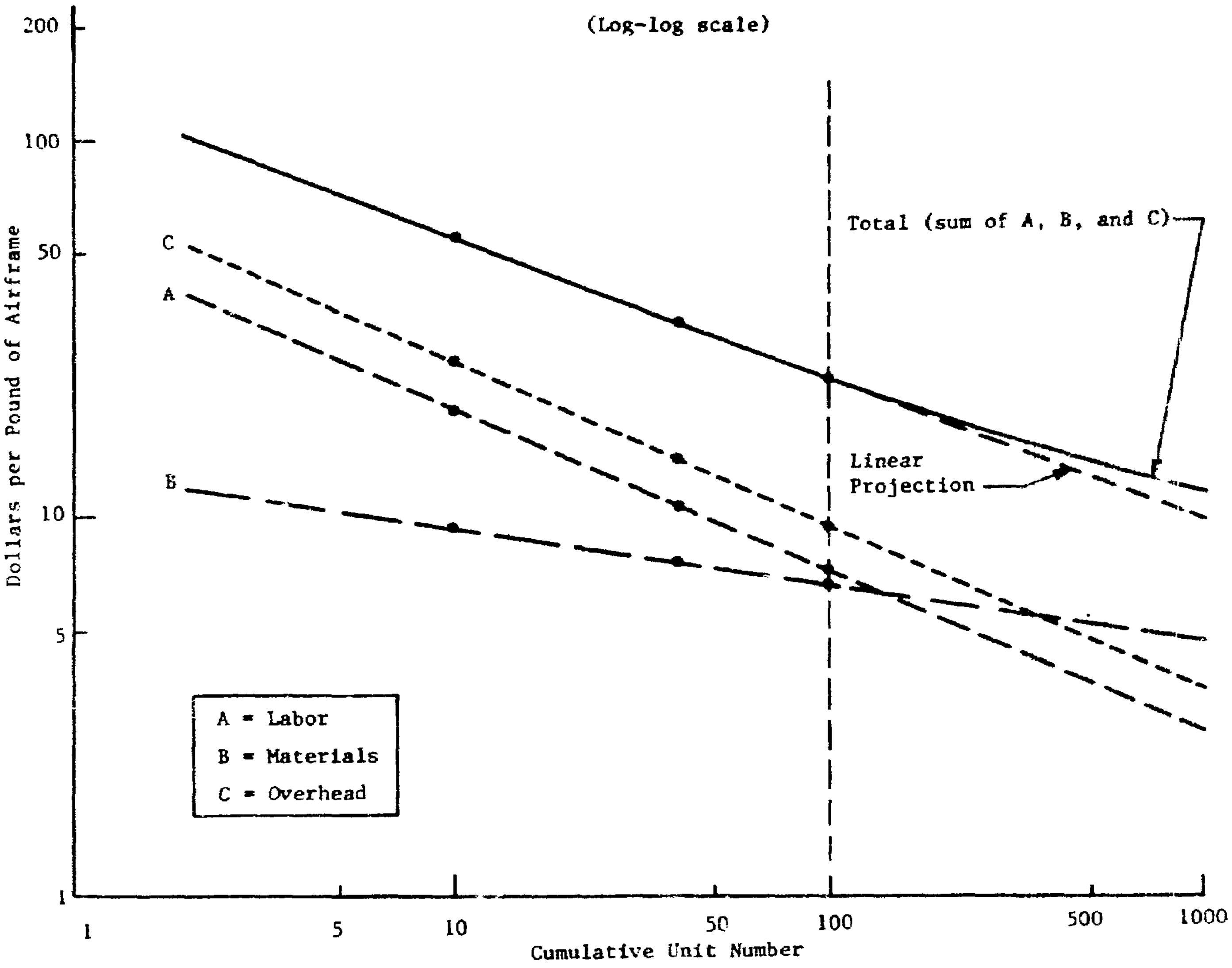

Fig. 14—Dollars per pound of airframe vs. cumulative unit number

curves increases still further for cumulative unit numbers beyond 1000.*

This example illustrates how going into slightly more detail can help in cases where the cost analyst has to work with a very small sample. A word of caution is in order, however. The reader should not generalize from our example and conclude that in all (or even most) instances the assembly of a more and more detailed data base will, in itself, make for better understanding of the problem.

The Use of Experiments to Broaden the Data Base

Sometimes the cost analyst finds that in a given problem area there is simply a void in the existing formal data base. This is likely to be the case when the planners are considering new proposals for distant future programs or capabilities requiring major equipments and/or operational concepts markedly different from those of the past and the present.

In some instances the existing set of estimating relationships can be used to conduct simulations which will furnish a first approximation to the cost of these proposed new capabilities. In other instances, however, the cost analyst cannot assume that the structural parameters in the existing set of estimating relationships are appropriate for the new activities being considered. He must therefore develop new relationships, or devise techniques for adjusting the present ones. But how does he do this if the necessary data base does not yet exist? One possibility is to see if any experiments are being conducted pertaining to the subject at hand; and if not, to try to initiate such an experiment. Let us consider one example briefly.

A number of years ago, cost analysts were confronted with the task of estimating the cost of the first generation of proposed stainless steel airframes for the mid-1960s. These proposals usually required rather extensive use of stainless steel honeycomb paneling, the production of which would involve a significant advance in the manufacturing

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*The difference is only about 1.5 dollars per pound at cumulative unit number 1000. At cumulative output 5000, the difference between the linear projection and the non-linear total curve is about 3 dollars per pound.

state of the art. The historical data base at that time was, of course, confined almost entirely to the experience accumulated in producing aluminum airframes, and little was in the formal records about the fabrication costs of stainless steel honeycomb panels--particularly large panels.

In the process of talking to the aerospace industry contractors regarding the problems involved in fabricating stainless steel structures, the cost analysts found that one of the companies was conducting a rather elaborate experiment. A special shop had been set up and numerous types of manufacturing operations were being performed on aluminum, stainless steel, and titanium structures. Taking aluminum as the base case, the objective of the experiment was to determine the probable incremental labor costs involved in working the other two materials for a representative sample of various types of manufacturing operations. Armed with these types of data from the experiment, the cost analysts were then in a position to devise techniques for adjusting the historical data base (aluminum experience) so that it would be more appropriate for dealing with the stainless steel airframe problem.

In visits to still other contractors' plants, the cost analysts found that several were experimenting with the construction of stainless steel honeycomb paneling. In sessions with the people conducting these operations the cost analysts obtained a wealth of information (both quantitative and qualitative) about how honeycomb cost might vary with core cell size and shape, shape and size of the panel, number of panel inserts, and the like. As a result, they were able to treat panels as a special cost analysis problem and hence to improve considerably their ability to estimate the cost of stainless steel airframes. The expenditure of time and travel budget on field work paid off well.

Summary Comment

Rather typically cost analysts supporting a systems analysis activity spend at least half their time struggling with the data and information problem. In this section we have tried to convey some flavor of the total problem and some notion of the types of techniques that may be employed to solve it. Basically what is required is ingenuity, persistence, and just plain hard work.

SUMMARY

Systems analysis forms the central core of a program budgeting activity. A vitally important part of systems analysis is a cost analysis capability to generate estimates of the resource impact of alternative courses of action being considered for the distant future.

Some of the principal characteristics of a systems cost analysis capability are:

1. An explicit relationship between inputs and outputs, with a strong emphasis on assessing the economic cost of alternative future output-oriented program packages.
2. Explicit treatment of uncertainty.
3. Provision for dealing with scaling considerations.
4. Explicit treatment of problems associated with time.
5. A recognition of the importance of sensitivity analysis, contingency analysis, and a fortiori argument.
6. Allocation of a substantial amount of time and effort to the continuous development and maintenance of an appropriate data base.

Establishing and maintaining a cost analysis capability to support systems analysis studies involves numerous difficulties. One of the most troublesome is the data base problem.

Solution to parts of the data problem may be through major overhaul of present formal information systems and through the establishment of new complete enumeration systems. This, however, does not appear feasible as a general solution--at least in the foreseeable future.

Short of such major efforts are numerous alternative possibilities. Some examples are:

1. Use of sampling techniques on an ad hoc basis.
2. Supplementing the existing historical data base by including estimated data points for the near future.
3. Statistical manipulation of the existing data base.
4. Obtaining additional information by conducting experiments.